REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
17 June 2013	Final	01 April 2012 - 31 March 2013

4. TITLE AND SUBTITLE
Numerical Studies on the Statistics of Acoustic Scattering from Rock Outcrops

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-12-1-0546

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
875 North Randolph Street
Arlington, VA 22203-1995

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; distribution is Unlimited

20130723005

13. SUPPLEMENTARY NOTES

14. ABSTRACT
An initial investigation of acoustic data has shown departure from currently used scattering theories potentially affecting the modeling of scattering statistics. An examination is needed of the connections between the rock outcrop geo-acoustic parameters and the resultant reverberation statistics. To aid in correctly understanding scattering from very rough elastic surfaces, effort needs to be put into addressing surfaces that are so rough that approximate scattering models are invalid. Results will provide a link in our understanding of false-alarm rates for target detection systems in rocky environments. Forming this link is necessary if we are to connect a physical description of the environment to weapons-frequency acoustic scattering statistics in the framework of physics-based clutter models.

15. SUBJECT TERMS
rock outcrops, clutter, false alarms, seafloor scatter

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	U	7	Anthony P. Lyons / 814-863-9895

Contract Information

Contract Number	Award Number: N00014-12-1-0546
Title of Research	Numerical Studies on the Statistics of Acoustic Scattering from Rock Outcrops
Principal Investigator	Anthony P. Lyons
Organization	The Pennsylvania State University Applied Research Laboratory

Technical Section

Objectives

Long term goals:

An initial investigation of acoustic data has shown departure from currently used scattering theories potentially affecting the modeling of scattering statistics. An examination is needed of the connections between the rock outcrop geo-acoustic parameters and the resultant reverberation statistics. To aid in correctly understanding scattering from very rough elastic surfaces, effort needs to be put into addressing surfaces that are so rough that approximate scattering models are invalid. Results will provide a link in our understanding of false-alarm rates for target detection systems in rocky environments. Forming this link is necessary if we are to connect a physical description of the environment to weapons-frequency acoustic scattering statistics in the framework of physics-based clutter models.

Objectives:

Several tests performed by the Applied Research Laboratory - Penn State (ARL/PSU) over the last decade at the test ranges of SHOBA and Nanoose have confirmed that failures caused by false targets were in areas of exposed rock. We propose to examine the connections between the rock outcrop geo-acoustic parameters and the resultant reverberation statistics via numerical models.

Concisely the proposed objectives are:

1. Examine the connections between the rock outcrop geo-acoustic parameters and the resultant reverberation statistics via numerical models.
2. Collaborate with NRL scientists as they proceed with their own numerical and tank studies as part of a highly-related project.

Approach

Model development:

We examined the connections between the rock outcrop geo-acoustic parameters and the resultant reverberation statistics via numerical models. To aid us in correctly understanding scattering from very rough elastic surfaces we expanded our efforts into the computational domain, allowing us to address surfaces that are so rough that approximate scattering models are invalid. Results of the numerical scattering work aided in this goal by providing a link in our understanding of false-alarm rates for target detection systems in rocky environments. Derek Olson, a current PhD student in the Acoustics Program at Penn State, developed numerical models and with the PI envisioned and ran numerical experiments which conformed to environmental and acoustics data sets collected in recent experiments.

Collaboration with NRL scientists:

NRL-DC scientists initiated a highly relevant and coordinated project on scattering from rock outcrops which will began last year. The proposed effort included collaboration with these NRL scientists to both inform them of any relevant results and to assess the validity of any developed models. We have worked in conjunction with Roger Gauss, Dave Calvo and Joe Fialkowski of NRL as they began and proceeded with their own numerical studies. The student involved in this research has spent time visiting with and sharing data with the NRL researchers as they have worked in their complementary project.

Progress

Work completed:

Over the course of the project work was performed by graduate student Derek Olson along with the PI on modeling scattering from rocky outcrops described in the first component listed in the technical approach described above. As virtually no information exists on scattering from rock outcrops, we have worked on obtaining relevant physical characteristics of rock outcrops, such as the roughness and morphology for use in models of acoustic scattering from rock. We compared numerical simulations to acoustic data that was collected using high-resolution acoustic data from a high-frequency imaging sonar. The sonar data analyzed this year was collected in April, 2011 during a joint field experiment that took place near Larvik, Norway, as part of a collaborative work with the Norwegian Defence Research Establishment (FFI). The SAS system operated at a center frequency of 100 kHz,, has a bandwidth of 30 kHz and was operated from the HUGIN Autonomous Underwater Vehicle (AUV). A sample SAS image of a rock outcrop in the experimental area obtained with FFI's SAS system and high-resolution bathymetry of the same area can be seen in Figure 1. From the Larvik, Norway, trial, scattering strength estimates were found to range from -5 dB to -35 dB over grazing angles of 0 to 90 degrees and yielded an approximate Lambert parameter of approximately -8 (very high). The measured scattering cross section from the leeward (or 'plucked') side exhibited variability on the order of 10 dB and probability of false alarm (PFA) curves were extremely non-Rayleigh with a 'knee' in the curves suggesting two scattering mechanisms were at work s will be discussed later in this report.

Because rough rock surfaces have a very large RMS height compared to the wavelength and do not conform to typical seafloor roughness models, such as the small-slope approximations (SSA), an approximate model that will predict the cross section is currently not feasible. Scattering behavior for these surfaces is driven by near-specular scattering from step facets, non-local shadowing by neighboring facets, diffuse scattering from convex corners and edges, and multiple scattering from concave corners of the surface. Approximate models cannot capture scattering from these types of surfaces and therefore were of little use as predictive models of the statistics of scattering. Given the inadequacy of approximate models we have investigated numerical models, specifically the boundary element method (BEM) to address which of the scattering mechanisms listed above were primarily responsible for the non-Rayleigh scattering statistics. Additionally, we began discussion and coordination with researchers at NRL on their related project, "Modeling of High-Frequency Broadband False Target Phenomena" (project PIs are Roger Gauss, Dave Calvo, and Joe Fialkowski). This collaborative work is continuing with exchange of data and ideas.

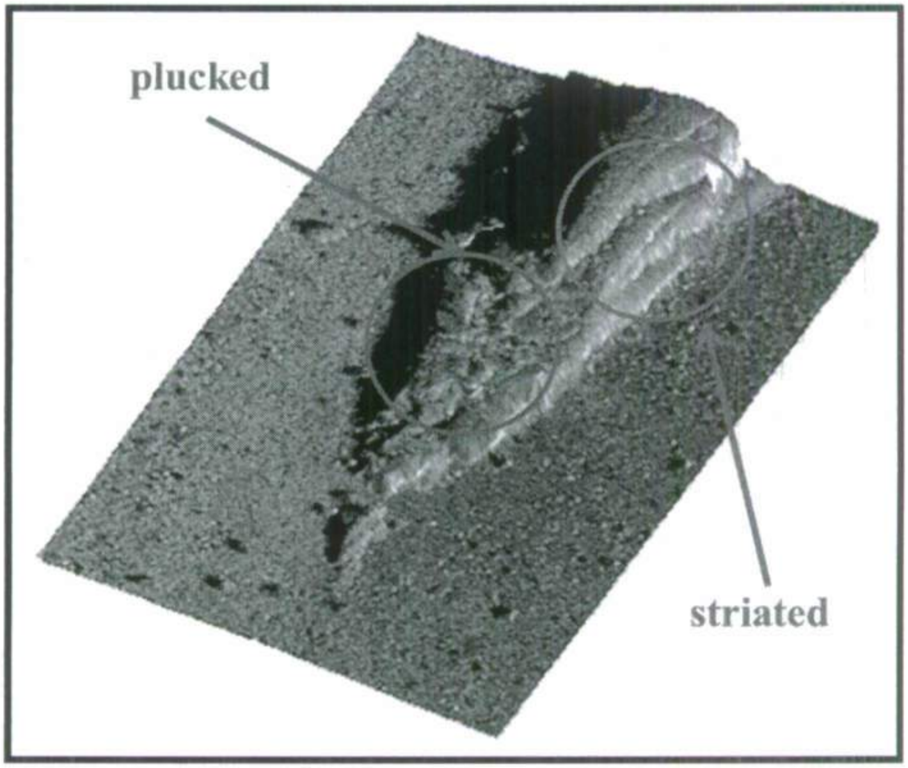

Figure 1. Example synthetic aperature sonar image (left) and high-resolution bathymetry from FFI's HISAS system taken during a joint experiment near Larvik, Norway in April, 2011.

Sample Results:

Surfaces resulting from glacial quarrying are composed of steps whose orientations and size distributions reflect the internal fault organization of the bedrock. A mathematical model of the leeward side of an outcrop can be generated to use in numerical simulations of acoustic scattering. Random stepped profiles can be simulated by generating horizontal and vertical segments, each with their own size distribution, then connecting them together. This surface model's input parameters are functions of the distributions of both the vertical and horizontal segments, and their appropriate parameters. The exponential distribution has been shown to describe field measurements of block size distribution in bedrock.

The BEM solves the Helmholtz-Kirchhoff Integral Equation (HKIE) by discretizing the boundary of a surface, and converting the integral equation into a matrix equation. In this research the boundary and surface pressure were described by piece-wise continuous linear elements whose endpoints are the nodes of the surface. At each node, the pressure depends on the pressure integrated over all other elements. If the HKIE is formulated at each point, then a linear system of equations can be formulated, and solved for the pressure, or its normal derivative, at each node and element. The resultant surface pressure and its normal derivative are then propagated to field points within the homogeneous medium. From this pressure at a field point, scattering strength can be computed as well as PFA for various values of kh and kL (mean vertical and horizontal facet scales times the acoustic wavenumber). To estimate the PFA, a histogram of the pressure amplitude at each angle, normalized by its variance is formed. The histogram is normalized by its discrete integral, and then converted to CDF by taking the normalized cumulative sum. Fig. 2 displays a set of BEM derived scattering strength curves for the facet surface model with varying kL and a fixed kh of 4. Predictions are close to the levels seen with in real data and are roughly Lambertian in shape, which was also seen in the real data. Fig. 3 displays PFA for the same surfaces and are clearly non-Rayleigh. The PFAs exhibit a concave curvature in log-linear space (a 'knee'), which is not possible with the K-distribution and is suggestive of that the data may require a combination of mechanisms (or mixture model) to fit the curve.

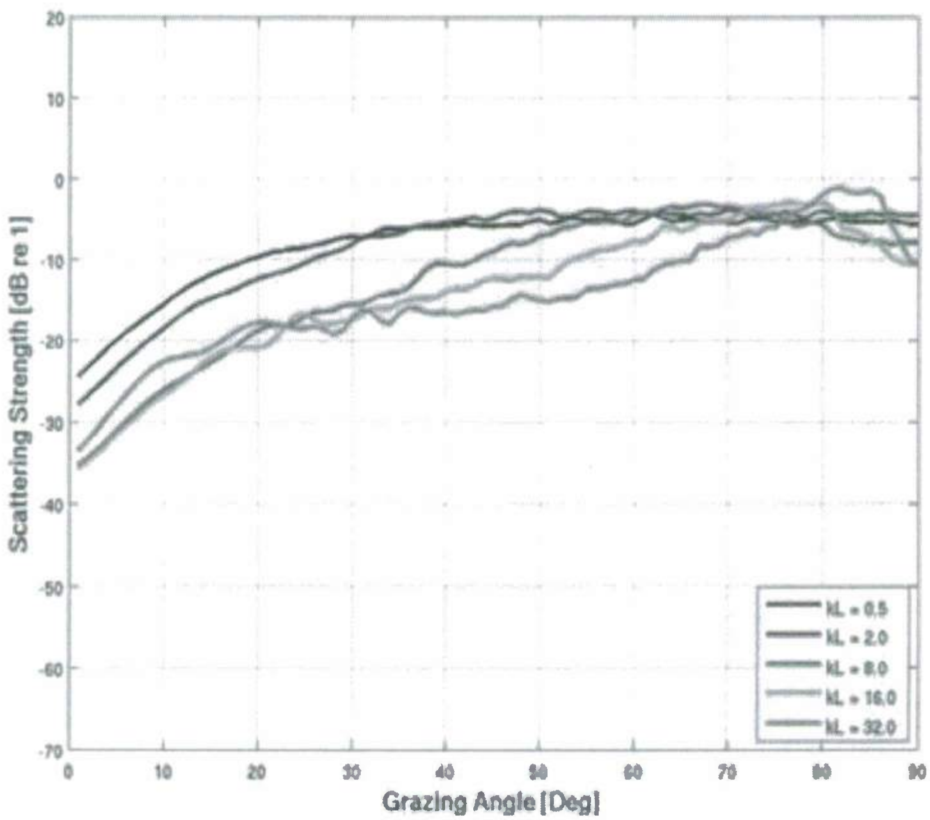

Figure 2. Scattering strength of rock outcrop obtained using BEM simulations with a facet model used for the rough surface.

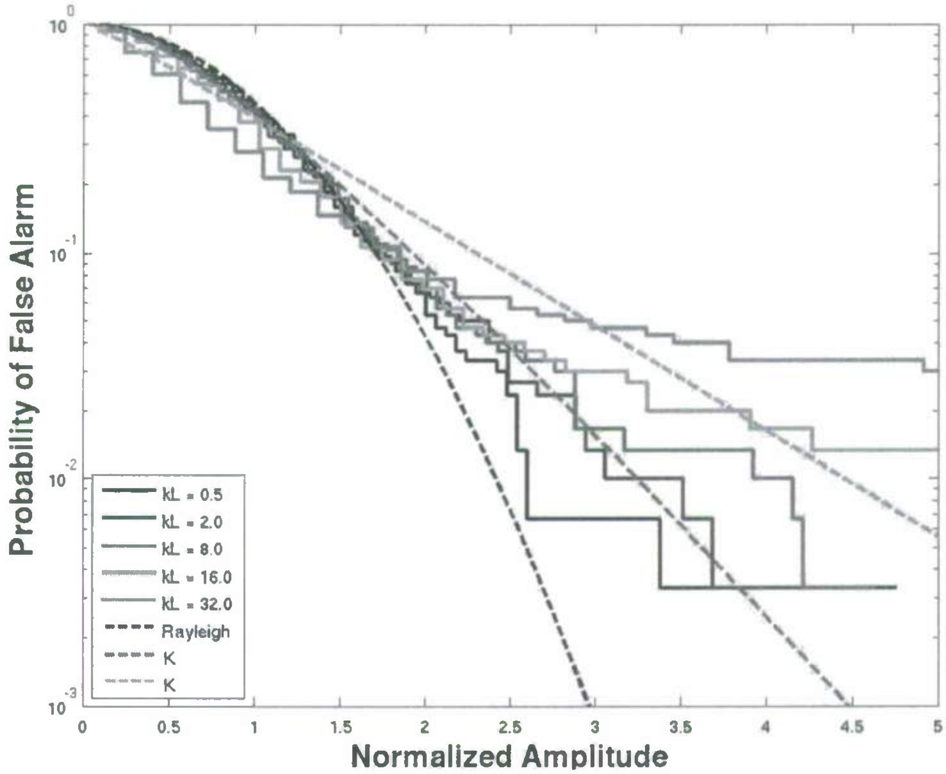

Figure 3. PFA of scattering from rock outcrop obtained using BEM simulations with a facet model for the rough surface.

Examination of the surface pressure distribution computed by the BEM can reveal clues to the dominant features responsible for the trends observed in the cross section and PFA curves. An examples of the surface pressure distribution for kh = 4.0 are displayed in Fig. 4. The incident pressure is directed from the upper left corner, towards the lower right corner at 45° (note that the vertical scale is exaggerated). In both plots, the facets facing towards the incoming wave have higher amplitude than facets pointing away. For certain facets, the maximum pressure amplitude is near the center of the facet, whereas for others, it is at the edge, near a corner. It is hypothesized that for facets with a maximum near the center, the dominant process is that of specular scattering from planar segments. For segments with the maximum near the corner, diffractions from the corner dominate. The determination of whether corner diffraction or specular scattering dominates a given facet is not clear, and may depend on its size, and relative position to other corners of the surface. Non-local occlusion may also be responsible for decreasing the amplitude of the surface pressure on a facet. True parameters for use in the surface model used in this research have been collected in a recent field experiment and are currently being analyzed.

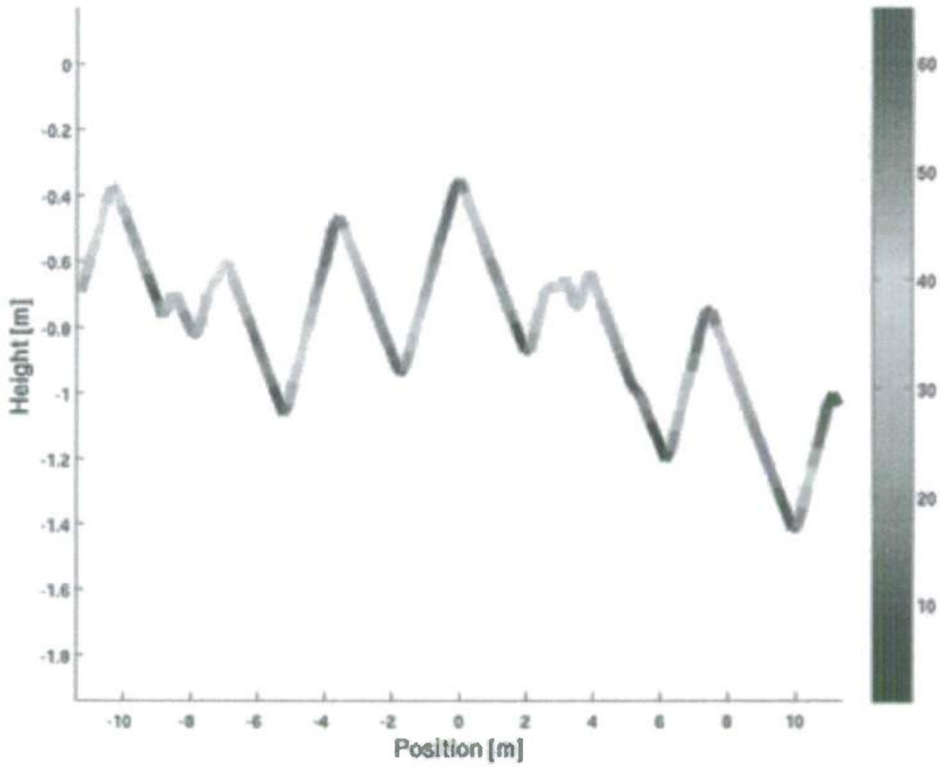

Figure 3. Example of the surface pressure distribution for kh = KL = 4.0.

Impact/applications:

The primary work completed over the course of this project consisted of developing techniques for modeling scattering from rough rock outcrop areas and comparing results with acoustic data sets collected from rocky areas. The proposed project was designed to increase our understanding of and simulation capability for weapons-frequency acoustic scattering from rock outcrops. This study resulted in useful knowledge of rock outcrops as a mechanism responsible for shallow water false alarms and how levels of false alarm relate to physical properties and features of the outcrops. Guidance relevant to this false alarm mechanism is being provided to researchers at the Naval Research Laboratory and will also be provided to those developing digital simulation content for the Guidance and Control (D&I) Modeling and Simulation TEAMS Initiative. Other deliverables are journal articles based on the conference presentations listed below.

Related Projects:

A related ONR project (Grant N00014-11-1-0546) is Characterization and Simulation of False Alarms Caused by Rock Outcrops. Program manager: Elroy S. Crocker, code 333.

Publications and technical presentations supported by this project:

Olson, D.R. and A.P. Lyons, 2011, 'Characterization and scattering measurements from rock seafloors using high-resolution synthetic aperture sonar,' The Journal of the Acoustical Society of America, 10/2011; 130(4):2349. DOI:10.1121/1.3654409.

Olson, D.R. and A.P. Lyons, 2011, Parameterization of rocky sea-floors using high-resolution synthetic aperture sonar, in Proceedings of 4th Underwater Acoustic Measurements Conference: Technologies and Results, Kos, Greece, eds. John S. Papadakis and Leif Bjorno.

Olson, D.R. and A.P. Lyons, 2013, Numerical simulation of acoustic scattering from very rough glacially-plucked surfaces using the boundary element method, in Proceedings of 5th Underwater Acoustic Measurements Conference: Technologies and Results, Corfu, Greece, eds. John S. Papadakis and Leif Bjorno.